Missouri Department of Natural Resources

Schematic Design Report

HVAC System

June 14, 2001
100% Schematic - Revision 1.1

General Approach

The first and foremost priority of the design team will be to provide a HVAC system that meets or exceeds all of the requirements of the building users. Within this framework the designers will work to deliver a system that uses significantly less energy than standard buildings, at least 40% less, and have indoor air quality that exceeds the ASHRAE standards. The design will strive to set new standards in performance, energy efficiency and indoor air quality at the same time as keeping the construction costs comparable to more traditional designs. Several innovative HVAC approaches will be used in this building. The key to these approaches is to use standard equipment applied in more intelligent configurations.

The overall approach will be to use smaller recirculation air handlers in the office areas with two dedicated 100% outside air handlers supplying conditioned, dry air from the roof. A high efficiency chiller, thermal storage system and a small cooling tower will provide the cooling to the air handlers and chilled water to the two outside air handling units. When additional dehumidification is required beyond what the medium temperature chilled water can deliver, DX coils in the outside air handling units will provide this cooling. The thermal storage will consist of the 'Nightsky' radiant cooling system that sprays water on the roof of the building at night and collects the water in a tank for use in the day. In addition, the building systems will be flexible enough to handle moderate natural ventilation through the opening of selected windows and will be able to provide adequate outside air economizer operation.

Air Handling

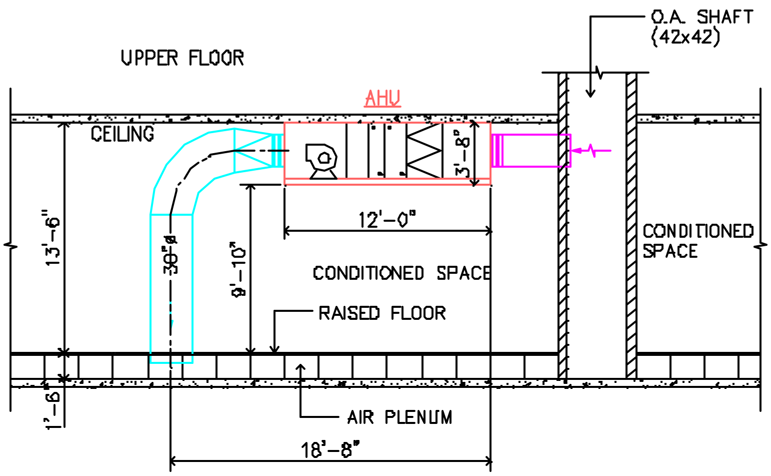
Air handling is central to delivering comfort to the building occupants. Air handlers normally consume half or more of the HVAC system energy. As such, air handlers are critical to energy efficiency of a building. In addition, air handlers are the delivery method of outside air and as such, play a central role in delivering excellent indoor air quality.

The air handling strategy will be based on two different types of air handlers. One will be air handlers that circulate air in the office and interior spaces. These interior air handlers will mix the outside air with return air, filter this mixture, heat or cool the stream and then deliver the mixture to the underfloor plenum. The second type of air handler will be dedicated to treating and delivering outside air into the space. In the spaces that are not delivering conditioned air through an underfloor plenum, the exact same process of mixing fresh and return air will take place. The only change for these spaces will be that the conditioned air will be delivered by overhead, exposed ducting.

Interior Air Handlers

The interior air handlers will serve the underfloor plenum as well as non-underfloor spaces such as the atrium and first floor west wing. The plenum supply fans will be controlled to maintain the ΔP measured from the plenum to the occupant space. Thus, for most any combination of occupant adjusted floor registers, the plenum will remain at the correct pressure for adequate flow throughout the space. In addition to this varied flow based on pressure, the air handler supply temperature will be reset based on a thermostatic control to the space. This reset will allow the plenum temperature during cooling mode to vary from approximately 62°F-68°F. In heating mode, the supply air temperature setpoint will be capable of varying from 74°F to 85°F.

Ceiling Mounted Interior Air Handling Unit



In order to adequately control the large space served by the underfloor interior air handlers, placement of the plenum control thermostat needs to be carefully considered. Our modeling of the air flow and temperature distribution patterns suggests that the location of the thermostat be on the building's Northern half at a distance of approximately 8 feet from the perimeter. Also, placement of the thermostat facing to the center of the space will avoid overexposing the sensor to the cooler perimeter zone temperatures.

The spaces that do not have an underfloor plenum will be served by smaller fan coils, the size of which will be determined in the DD phase of the project.

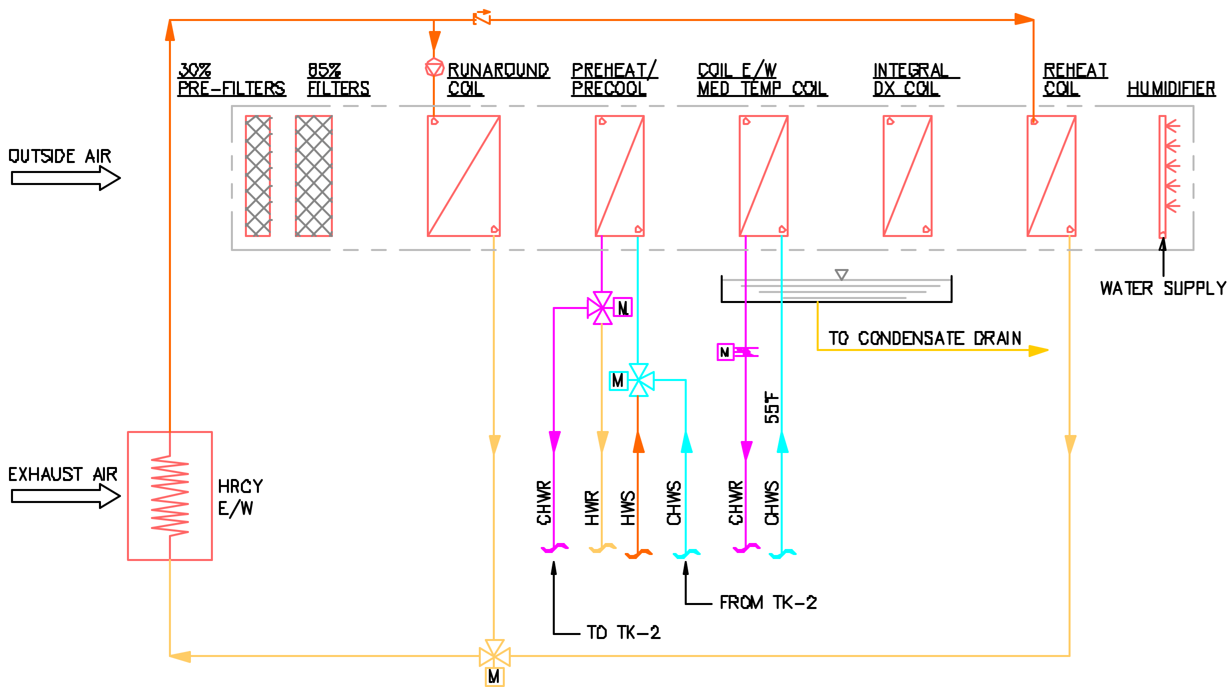
Key Interior Air Handler Specs:

- Low velocity through air handler: 250 fpm target; eliminate need for sound attenuation.
- Low total static pressure: 1.5" target.
- Space Cooling Air Handlers – target efficiency of at least 4,000 cfm per kw
- Variable Frequency Drives – controlled to the underfloor-to-space pressure differential or to thermostat in overhead zones
- 24+ Overhead Air Handlers – 4000 to 6000 cfm, 4-pipe (Heating and Cooling), ceiling mounted, custom units that will save crucial floor space (see Underfloor Air Handler Specification Sheet)
- Possible Suppliers – *Norman Wright, Engineered Air, Metalform*

Outside Air Handlers

The two outside air handlers will serve four main purposes. They will provide the ASHRAE minimum outside air quantities plus some based on CO2 sensors in the space. Secondly, the two units will use integral DX cooling coils to effectively dehumidify the outside air. Lastly, the units will be capable of a nighttime purge. This purging process will replace all the air in the space as well as pre-cool the building with cool nighttime air.

Outside Air Handler



Controlling the amount of outside air to the building is fairly easy. The outside air unit's supply fan will be fitted with a Variable Frequency Drive (VFD). The VFD will control the outside air supply to a constant pressure setpoint measured upstream of the unit. Individual motorized dampers located at each fan coil will be appropriately opened or closed to control the space humidity and oxygen requirements based on readings from one of the eight CO2 and RH sensors. The humidity and CO2 monitoring equipment will be located in the return grill of the air shaft on each wing of each floor, allowing easy installation and maintenance. For example, in an unoccupied wing with reasonably low humidity levels, the amount of outside air would be minimized. But, if this zone were to become too humid or depleted of oxygen, the motorized outside air dampers on each fan coil unit would open to allow more dry, clean air to enter the space.

Cooling Mode

The outside air units will condition the often wet, hot air in an efficient manner that will provide neutral and dry air to the duct @65F. This will be achieved by a series of coils shown in the above figure that make use of the thermal storage, exhaust air and medium temperature chilled water. In the cooling mode, the exhaust air heat recovery is by-passed and the incoming warm air is pre-cooled by the run-around coil. After leaving this coil, the air is then pre-cooled further by the heating/pre-cooling coil. This coil is served by tank-2 that contains medium temperature chilled water produced by the Nightsky system. When adequate pre-cooling is not effective, the 55^{o}F Chilled Water Coil can be used to bring down the air temperature near or below the dewpoint. Having pre-cooled the air to a low temperature, the energy intensive DX coil finishes the cooling/dehumification process by droping the air to a low dewpoint of approximately 45^{o}F. Finally, the now dry, cold air is reheated by the glycol loop in order to avoid low duct surface temperatures that can cause condensation I the space.

<u>*Heating Mode*</u>

In heating mode the building exhaust is used to pre-heat the cold winter air. This is achieved by by-passing the reheat coil and looping the glycol from the run-around coil through the air-to-glycol heat recovery unit. After using the building's exhaust heat, the air enters the double acting heating coil that serves as an additional pre-coler in the summer months. At this coil, the air receives the majority of its heat. For some conditions, this heated air will be very dry and will required humidification before the variable speed fan pushes the conditioned air to the space. This process makes use of the exhaust air heat and thus saves energy in the heating mode.

Important Outside Air Unit Notes:

- Use 4" 30% pre-filter on make-up air handler and 12" mini-pleated 85% filter on all air handlers; 0.3-0.4" pressure drop across filters.
- Heat recovery from 2 of the 3 exhaust streams to pre-condition outside air.
- Air-side economizer operation for use when outdoor conditions and building load
- Run-Around Coil, Pre-cooling/Heating Coil, Medium Temp CHW Coil, DX Coil and Humidifier
- Outside air handlers – 3000 cfm per kW
- CO2 and RH sensors for demand controlled ventilation
- Nighttime purge
- VSD on Supply Fans controlled to the supply duct pressure
- Possible Suppliers – *Des Champs, Carrier*

Chilled Water System

The chilled water system will be set-up for efficient operation as well as flexibility. The chiller is sized to handle the full building load on its own, but supplemental, efficient systems will be in place to relieve the chiller and drastically save cooling energy. The variable speed, centrifugal chiller will be in line with a chilled water storage tank that can be "charged" with cool water at night. The thermal storage capacity of the tank in combination with the associated roof spray system will provide over 30% of the yearly cooling to the building.

In addition to the large thermal storage capacity of the chilled water tank, a smaller tank will be used for "medium temperature" (65-75 deg F) chilled water. Therefore, if nighttime air conditions will not allow for 100% chilled water storage at the normal 55 F temperature, this second tank will be able to store warmer water for use in pre-cooling the outside air (see Outside Air Handler drawing).

Furthermore, the tower will be connected directly to the chilled water system so that effective water-side economizing can be implemented. Of course, there will be periods of the year where no cooling can be passively stored at night making water-side economizing impractical. In these situations, the highly efficient centrifugal chiller will provide the cooling. Its operating efficiency will be high since the cooling tower will be set to deliver the coldest water practical to the condenser. In addition, the chiller will be delivering 55 F chilled water as opposed to the normal 45 F, which will add to the system's low energy consumption.

Chiller and Chilled Water Pumping

Ideally, the chiller could be downsized to handle the portion of the load that the roof spray cooling system can not create. Unfortunately, the roof spray is less effective during warm, humid nights. Therefore, during the peak cooling season, the chiller may have to operate at peak loads in times where the 'free-cooling' of the roof spray is ineffective. Fundamentally, the chiller will be so efficient that without the added load relief of the passive roof spray, the energy consumption of the chiller will rival the most efficient equipment available.

Also, during summer periods of high daytime cooling demand and warm, humid nights, the chiller may be operated at night to store chilled water in the Nightsky holding tank. Chillers general operate marginally better at night since the outside air temperature is lower than during peak cooling days. Thus, using the chiller to store cooling potential at night can save a little energy, but more importantly can shave off expensive peak electrical loads during times of expensive energy.

For years, constant volume primary chilled water pumps were standard. The new direction for energy savings is to use variable speed, primary only pumping to deliver the chilled water to the load at a set pressure. To solve the issue of the chiller's required minimum flow, a by-pass line similar to a standard primary-secondary system will be implemented. The flow through the by-pass line will vary depending on how much flow is measured exiting the chiller evaporator. Therefore, if virtually no cooling is required, the primary pump will be running at its minimum rpm, maintaining pressure at the cooling coils while the by-pass valve opens accordingly to maintain the chiller's recommended minimum evaporator flow.

Important Chiller and Chilled Water Notes:

- Oversize pipes and chiller barrel; target pressure drop of 7' through chiller and 40' on total pumping system for both chilled water and condenser water sides
- Primary only chilled water pumping.
- Two-way valves for variable flow control; no circuit-setters or flow controllers; monitor and alarm discharge temperature on variable flow air handler to detect valve failure.
- Minimize piping accessories and excessive pressure loss configurations; no end suction diffusers.
- Use check valves, no triple duty valves for balancing.
- Chiller Full Load Efficiency – 0.40 kW/ton
- Suggested Supplier - *York*

Cooling Tower and Water Side Economizing

The cooling tower will be oversized such that lower condenser water supply temperatures can be obtained. The lower approach temperatures from this design will allow the chiller to operate at a much higher efficiency. Also, this over-sizing will account for any additional cooling loads from future computer room installations or other additions to the load.

The low approach temperatures will also aid in water-side economizing. On cooler days where the internal load of the building requires cooling, the tower will be able to provide 55deg chilled water. This action will relieve the chiller and save energy. The weather data from Jefferson Memorial Airport shows over 200 hours where effective water –side economizing is available from the system.

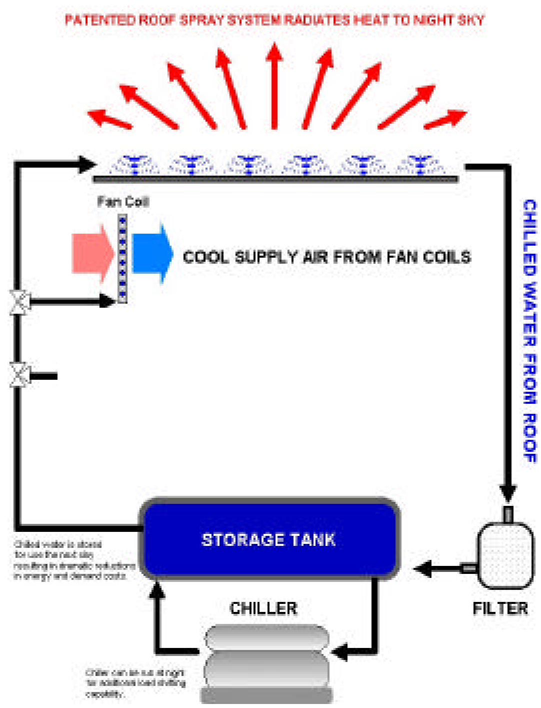
Important Cooling Tower Notes:

- The tower fan will operate on a VSD
- Optimize Chiller Efficiency - control for a floating condenser water supply temperature 3°F above outside wet-bulb temperature with a minimum temperature based on chiller requirements.
- Condenser water piped through a low pressure drop plate and frame heat exchanger for water-side economizing.
- Possible Suppliers – *Aqua Loop*

The Nightsky Roof Spray System

Creating chilled water by using cool ambient conditions saves energy by not requiring frequent chiller operation. Similar to water-side economizing with the cooling tower, the Nightsky system also takes advantage of the free cooling ambient conditions. The difference is that this system operates at night with very little energy and stores all the cooling power in the form of chilled water. Therefore, when building cooling is not required (nighttime or cool mornings) the system will be working to store cooling for when the building does demand cooling.

NightSky Integrated Cooling System



The roof spray system is supplied by Davis Energy Group and consists of the control hardware/software, filters, pumps and design to accommodate all applicable weather concerns. The general strategy is to obtain as much of the building's daytime cooling load as possible by evaporating and radiating heat from a film of water sprayed on the roof. The cooled water is then collected in one of two tanks for use hours later during daytime cooling. And since the system uses small pumps, the operating efficiency of the system easily exceeds a similar system using the cooling tower for chilled water creation.

When nighttime conditions do not permit Nightsky water of 55°F or lower, a second, smaller tank will be used to store any "medium" temperature water that can be created. Therefore, the Nightsky system will be able to store cool fluid over a larger percentage of the nights. On the same nights that the Nightsky roof spray cannot create 55°F water, rather 60°F -75°F water, the following day's outside air temperatures will most likely be high. Thus, the medium temperature stored water will be used for pre-cooling the incoming make-up air (see Outside Air Handler section).

The one drawback to the Nightsky free cooling method is that a large chilled water storage volume is required. Estimates for the 55^{o}F tank (tank-1) are 34,000 gallons with the medium sized tank being ½ to 1/3 of tank-1's volume. A lower cost approach for these tanks has been studied by Davis Energy Group, in which the tanks are built into the building's slab. Each tank would be roughly 10-12' in width, 6-7' in depth and vary in length and run east to west under the building's 1st floor slab. An added benefit of this design is that the tank's slow heat gain through the top surface would work to cool the 1st floor above it. Therefore the placement of the tanks under the slab is a less expensive and a more energy efficient alternative than conventional tank placements.

Notable Items:
- Spray Nozzle array to cover over ½ of the roof area (approx. 15,000 sqft)
- Sand filter with automatic backwash will provide the particulate filtration
- Control Algorithm to predict daytime cooling requirements will be provided
- Supplier – *Davis Energy Group*

List of References:
1. Lance Porter – Tall Weather Glazing – Vacaville, CA – Winner of the 1999 ASHRAE Technology Award – 707-452-1600
2. David Linerauski – Pacific North West National Laboratories – Richmond, OR – 509-372-4461

Heating

Since the building requires heat for at least half of the year, the efficiency of the boilers and domestic hot water system are just as important as the chilled water system. In fact, as gas prices continue to rise, efficient natural gas boiler design is critical to building performance and annual operating costs. To achieve this, a series of boilers that are staged efficiently will be used to provide the building with hot water. For the domestic hot water system, solar panels have been designed to contribute over 50% of the needed load on an annual basis.

Solar and Domestic Hot Water System

The original plan of using Solar Hot Water Panels to supplement the building's domestic *and* space heating hot water systems is impractical, considering the scale of the solar area needed in the winter for heating. The winter season, when the building needs the most heat, is coincident when the gain from Solar panels is at the annual lowest. Therefore a reasonable, cost-effective alternative is to implement solar hot water panels for domestic hot water heating only.

A calculation of the domestic hot water system requirements show that 120 sqft of panels will provide over 50% of the building domestic hot water requirements. The 8'x4' panels will be tied into a closed loop glycol loop for freeze protection. This loop would cycle on and off to maintain a high temperature in the solar hot water storage tank (tank-3). As hot water is used, cold make-up water is pushed into the hot solar tank and is either preheated or fully heated before entering the conventional gas hot water heater. Although the gas savings of 185 therms does not equate to an large annual savings, the concept of using solar heat is one that can be demonstrated to visitors and occupants for educational purposes.

Domestic HW Notes:
- (4) 8' x 4' solar panels to supply over 50% of the domestic hot water heating requirements
- Adequate storage tank and 90% efficient conventional HW heater in series with the solar tank
- Recirculating HW to provide immediately HW to the outlets
- Suggested Supplier – *Heliodyne Solar Systems*

Space Hot Water Heating

The hot water system will supply hot water to the heating coils at approximately 180°F with a design ΔT of approximately 30°F. Three firetube boilers of will make-up the heating system with each being 35% of the peak load design. The calculations for the boiler sizing are based on a winter set-back thermostat of 15°F and a morning warm-up period of 1 hour.

The use of three boilers will not only provide critical standby capacity for maintenance and possible failure, but will enable the control system to cycle and stage the additional boilers at appropriate times to maximize efficiency. The staging of the boilers is important since a majority of the building's base heating load is equal to the size of only one of the boilers.

Hot Water System Metrics:

- (3) High Efficiency, Firetube Boilers
- 88% Full Load efficiency
- 180°F Hot water supplied to 24+ fan coils and both outside air handling units
- Suggested Supplier - *Locinvar*

Perimeter Reheat Strategy

In order to reduce first cost and energy efficiency, the idea of perimeter reheat has been carefully analyzed to justify the removal of much of the building's perimeter reheat. The concept is simple. If the building envelope is thermally efficient and the occupants are located at a small distance from the exterior walls, the effect of the cooler or warmer perimeter zone will be negligible on the occupants.

Based on standard practice, a heating mode space temperature of 72°F and a cooling mode setpoint temperature of 75°F have been defined. The cooling 1% ASHRAE design criteria for the area is 92°F, with a 76°F coincident wet-bulb temperature. The heating criteria specified for the 1% ASHRAE design is 5°F. Based on these parameters and an estimated 4.5' perimeter zone, separated by a cube wall, a 2-D computational fluid dynamics (CFD) simulation was created. In addition to the CFD model, a simulation of the North-facing perimeter zone was computed in DOE-2. DOE-2 outputs are trusted for energy reports and for specific equipment sizing, but the program fails to account for the mass transfer or "mixing" that the CFD model considers. Summaries of both analyses are shown for comparison and evaluation.

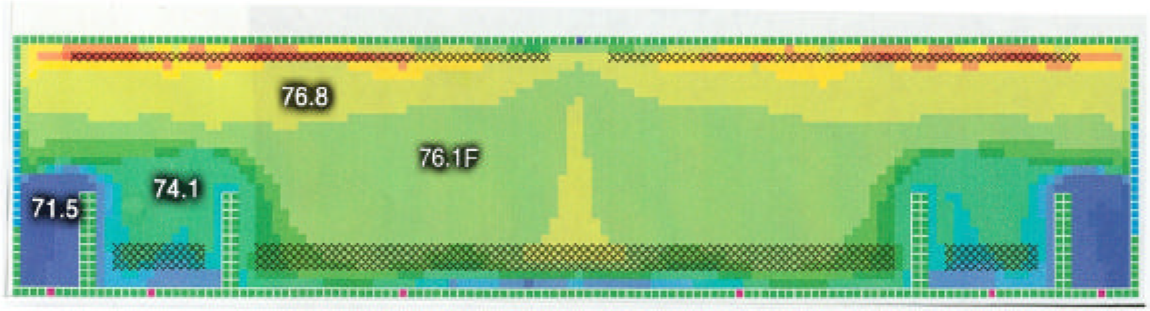
Computation Fluid Dynamics Model

The CFD model, created in the software TAS, is shown below for the winter design conditions. The winter design conditions are the most likely case of large temperatures variations from the perimeter to the core. A list of the assumptions/inputs is shown below for completeness.

1. Efficient Windows - U = 0.21 BTU/hr-sqft-°F
2. Isothermal Walls - @ 72°F
3. 4.5' Perimeter zone with 5 ½ feet high cube walls

The location of the underfloor jets are shown as red dots in the raised floor and the return air path is conservatively modeled as being in the center of the space. The 70' cross-sections shown below represent 3 different conditions of the space at varying plenum supply temperatures.

Case 1 – Plenum Supply Temperature of 72°F

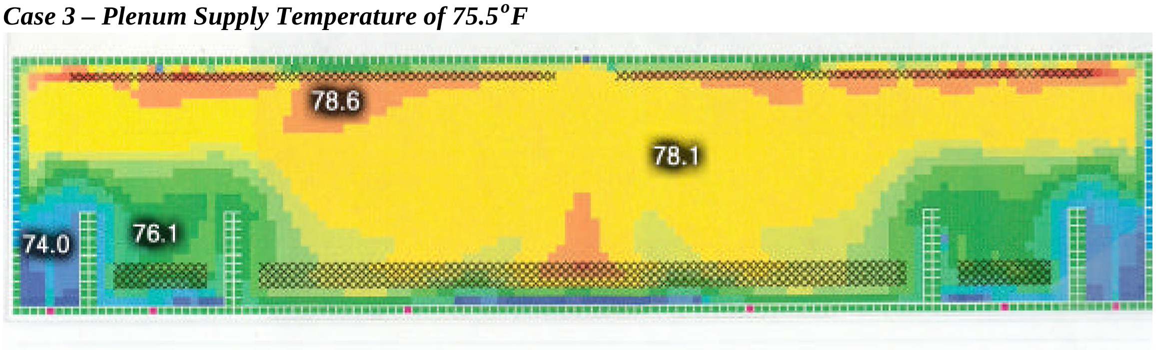


This case illustrates that a potential 4.6°F temperature difference exists between the perimeter and the interior. The actual occupant temperature difference is only 2 °F which is within normal thermostatic setpoint accuracy. Notice that the 5 1/2 foot tall cube plays an important role in keeping the cooler perimeter away from work space.

Case 2 – Plenum Supply Temperature of 73.5°F

With a slightly higher plenum supply temperature, the entire section heats. In actually the flow in the core of the building would be occupant adjusted to mitigate this heating. The important thing to note is that although the core-to-perimeter temperature difference has increased to 5.1°F, the outer occupant to core temperature difference remains below 2°F. Again, this difference is noticed, but remains within the accuracy of most space setpoint conditions.

Case 3 – Plenum Supply Temperature of 75.5°F



As the plenum supply temperature increases, the entire section heats. The perimeter space temperature rises closer to the core temperature. At this point the core temperature would be too hot for most occupants and the two diffusers in the core would be turned down or off completely. As stated in the Interior Air Handler portion of this report, the thermostat for each Fan Coil Unit should be located on the inner side of the outer occupant workspaces. The prime target location for this installation is 6’ to 8’ from the North wall to accurately measure conditions experienced by the occupants near the perimeter zone.

Based on the cases studied above, the temperature variations throughout the occupied areas in the space do not call for reheat. If future churn of the occupants is such that perimeter zone reheat is required, a perimeter reheat retrofit should be a fairly easy adjustment. In order to minimize future retrofit costs, each wing on each floor will have stub ends to accommodate added hot water piping and terminal reheat boxes. There are boxes with fan coils for forced air and other models that use the pressurized plenum to push the air to the perimeter zone. The option without the fan is more efficient and should be specified in future retrofits.

DOE Output

A double check of these temperature variations was done using Visual DOE 3.60. In the DOE model, a North facing perimeter of 5‘ was created to model winter cooling effects. The output of the DOE model as shown below defines the calculated number of hours that the zone is in various temperature regimes during all annual hours. Although the program calculates temperatures in the zone for all 8760 hours of the year, the hours shown in this report reflect hours in which the building is occupied.

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1Green Design Tools VisualDOE                                                  DOE-2.1E-113  Tue Jun 12 20:43:07 2001SDL RUN  1
 Eff, 2 Pane, R-19, 76 c, 72 h no reheat Files\GDT\VisualDOE\Projects\DNR_rev13_7VisualDOE ver 3.0.90
 REPORT- SS-O  TEMPERATURE SCATTER PLOT  System_704      FOR Room_8_C                        WEATHER FILE- Columbia  MO     TMY
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                                        TOTAL HOURS AT TEMPERATURE LEVEL AND TIME OF DAY

                HOUR    1AM 2   3   4   5   6   7   8   9  10  11  12   1PM 2   3   4   5   6   7   8   9  10  11  12   TOTAL
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         ABOVE 85         0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0       0

         80-85            0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0       0

         75-80            0   0   0   0   0  75  96 126 143 168 177 186 191 198 199 194 186 140 121  99  83   0   0   0    2382

         70-75            0   0   0   0   0 101 207 177 160 135 126 117 112 105 104 109 117 133 130 152 168 105   0   0    2258

         65-70            0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0       0

         60-65            0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0       0

         BELOW 60         0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0       0

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                                  *                                                              *
                                  *  NOTE  1)THE TEMPERATURE COUNTS ARE MADE ONLY FOR            *
                                  *          THE HOURS WHEN THE FANS ARE ON                      *
                                  *                                                              *
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The numbers in each temperature “bin” are consistent with CFD modeling for similar cases. Both computer models indicate that the concern of perimeter temperatures dropping below comfort levels is unfounded. Of course, decreasing the efficiency of the envelope materials could dramatically increase both annual energy consumption and temperature variations from the perimeter to the building core.

In conclusion, our analysis shows that perimeter reheat is not needed in the open office areas. Although the unblocked, open conference area perimeters will need reheat, others areas will be able to appropriately maintain minimal temperature variations. This temperature variation should be less than 3°F during extreme outside air conditions.

Indoor Air Quality

Indoor air quality will meet or exceed ASHRAE Standard 62-1999. This will be achieved by using high efficiency, high quality filters on both the outside air and return air paths. The outside air volume control will consist of CO2 sensors, RH sensors, motorized dampers and space conditioning shut off limitations. In addition to these features, a nighttime purge will pre-cool and fully replenish the fresh air in the building during applicable nights.

The outside air, delivered to the fan coil units at 65°F and at a relatively low %RH, will be filtered by a 30% and 85% pleated filter. This air will be controlled to provide adequate CO2 levels in the zone as well as provide dehumidification in the space. At times of high humidity in the space, the RH sensor will call on more, dry, conditioned outside air. When the outside air dampers are fully open and additional humidity control is required a signal to the occupants should be installed that warns them of the situation. Humidity levels should only become an issue if occupants leave windows open at times of high outside air humidity and heat. Therefore, if those in the space are educated on when to close windows, humidity concerns should be adequately addressed. A manual shut-off of the zone should also be considered on days or hours that the occupants would rather have outside air cooling through open windows. Since there are not a large amount of hours where this type of operation is practical or a large amount of operable windows, a simple shut-off the air handling unit should be sufficient.

Key Air Quality Points:

- Meet or exceed ASHRAE Standard 62-1999.
- 30% in line with 85% filters on all outside air entering the building
- 30% filters on all air being delivered by the fan coil units
- RH sensor for Outside air control – control O.A. volume by RH first followed by CO2 sensor
- CO2 sensors for Outside air volumetric flow variations
- Nighttime Purge during acceptable outside air conditions

Plumbing

There are many ways to reduce the amount of water consumed in an office building. The Nightsky system is designed to collect sprayed water on the roof. With this collection system all ready in place, gathering rainwater in an overflow situation for use in toilets is an exceptional water saving concept. In addition to collecting water for use in waste disposal, the toilets will be low-flow, pressure assisted and all urinals will be waterless. These two concepts together will dramatically reduce city water use.

Water Conserving Concepts:

- Waterless Urinals
- Low-flow, pressure assisted toilets
- Rainwater collection and filtration for use in toilets
- Low-flow, efficient shower heads
- Proper, environmentally conscious, landscape architecture will insure that all specified vegetation is in the proper habitat. The design of these indigenous species will help avoid unnecessary.

Notable Efficiency Items

In order to meet the target of exceeding a typical building built to ASHRAE Standard 90.1-1999 by a target of 40-50%, measures to implement efficient equipment will be addressed. Since the majority of the HVAC energy will be used in the ventilation, all fan coil units will have a target efficiency of 4000 cfm/kW. Also, each fan coil will be VSD controlled to the ΔP in the underfloor plenum. Therefore any variation in occupant controlled diffuser output will alter the fan coils energy consumption accordingly. Also, smaller area-specific conference rooms should be equipped will variable volume underfloor diffussers. These diffusers will open when needed to satisfy cooling/heating and when motion is detected. *York International's* "Flexsys" product is energy efficient, modular and well proven.

Other efficiency items that will contribute to the building's overall energy reduction include:

I. Thermally Superior Envelop Materials
   1. Walls >R-19
   2. Roof =R-30
   3. Windows; U = 0.22 BTU/hr-ft^2-^{o}F
   4. External Doors; U < 0.60 BTU/hr-ft^2-^{o}F
   5. Skylights; U < 0.48 BTU/hr-ft^2-^{o}F

II. Multiple Coil, Heat Recovering Outside Air Units

III. Nightsky System – 30%+ reduction of total chiller energy use

IV. Solar Hot Water panels for 50%+ of domestic HW heating requirements

V. Water-side Economizing through Cooling Tower and Heat Exchanger

VI. Highly Efficiency Chiller
   1. Centrifugal type operated with a VSD on compressor
   2. operating at low CWS temperatures
   3. over-sized condenser and evaporator barrels
   4. supply of 55^{o}F chilled water over the normal 42-46^{o}F

VII. Underfloor System
   1. Lower pressure drop through air handlers
   2. Ability to supply medium temperature chilled water

VIII. Interior Air Handlers
   1. Low static pressure of 1.75" max
   2. Low coil face velocity <300 fpm
   3. VFD operation to minimize fan energy
   4. 4000 CFM/kw efficiency

IX. Outside Air Flow Control to insure lower energy use of the Outside Air Units

X. Efficient Boilers capable of 88% efficiency at full load

XI. Minimum of perimeter reheat in the building
   1. Stub ends provided for future retrofit
   2. Keep occupants in non-reheat areas 4'+ from exterior walls

XII. Variable Air Volume Underfloor diffusers in Conference/Meeting rooms
   1. Controlled to motion sensor and load requirements
   2. Automatic operation

XIII. Potential Wind Power and/or Photovoltaic Energy Sources

Benchmark Metrics

The following list of metrics sets targets for what efficiencies are required for the design to meet and exceed ASHRAE standards. In order to insure that the design criteria for energy end use is met, this table outlines key efficiency targets.

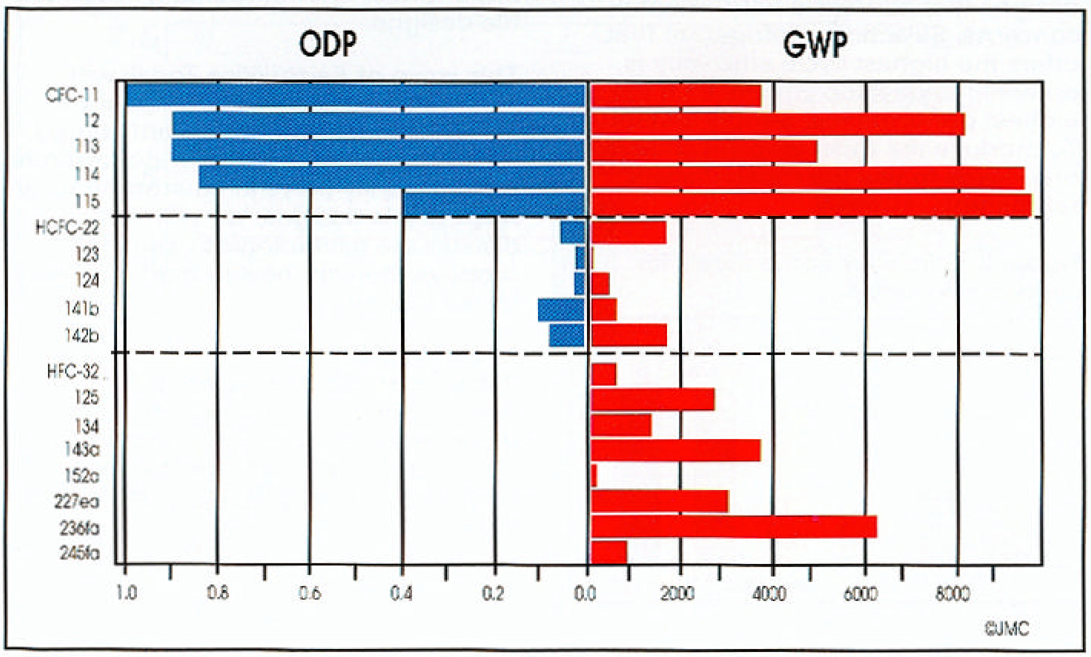
Metric	Units	DNR Target	Typical Building w/ASHRAE 90.1
Chiller Efficiency	KW/ton	0.40 kW/ton	0.64 kW/ton
Chilled Water Pumping Efficiency	KW/ton	0.026 kW/ton	0.100 kW/ton
Chilled Water Pump Efficiency	%	85%	65%
Condenser Water Pumping Efficiency	KW/ton	0.026 kW/ton	0.100 kW/ton
Condenser Water Pump Efficiency	%	85%	65%
Cooling Tower Efficiency	KW/ton	0.03 kW/ton	0.05 kW/ton
Office Space Air Handlers	CFM/kW	4,000 CFM/kW	1,120 CFM/kW
Office Space Fan Efficiency		80%	60%
Outside Air Handler Fans	CFM/kW	3,000 CFM/kW	790 CFM/kW
Outside Air Fan Efficiency		80%	60%
Office Space Air Handlers	KW/ton	0.18 kW/ton	0.68 kW/ton
Outside Air Units	KW/ton	1.09 kW/ton	1.41 kW/ton
Cooling Density	SF/ton	>550 sqft/ton	400 sqft/ton
Outside Air Design Flow	CFM/person	30 (max) w/CO_2 Sensor	15 CFM/person
Total Air Movement Flow	CFM/sf	1.2 CFM/sqft	1 CFM/sqft
Boiler Efficiency	%	85%	77%
Water-Side Economizing	hours	200+ hours	Non Required

Environmental Issues

The Montreal Protcol has forbid the use of CFC refrigerants. These types, such as R-11 and R-12 have the greatest environmental impact on the atmosphere and should therefore remain unusable in designs. As shown in the chart below, different types of refrigerants carry far different Global Warming Potential (GWP) and Ozone Depleting Potentials (ODP). Both quantities adversely affect the environment, but the impacts of both should be weighed to consider the application in which the refrigerant is being used.

In the case of a standard chiller, the only real commercially viable options are R-123 and R-134a. Although some might compare the ODP of the two and quickly choose R-134a over R-123, it should be noted that there is an efficiency penalty on all equipment of 3-5% when using R-134a over R-123. Therefore, although the R-134a has zero ODP, the gases emitted from power plants to make-up the efficiency loss between the two could make the decision slightly harder.

Figure 1: ODP vs GWP for common refrigerants and candidates.



Rumsey Engineers recommends using R-123 for all specified chillers. The measurement of the Total Equivalent Warming Impact (TEWI) for both refrigerants R-123 and R-134a is almost identical. The TEWI factor includes expected additional green house gas emissions from fossil power facilities. These facilities would theoretically need to produce 3-5% more energy over the refrigerant's life to make up the loss in efficiency if R-134a were chosen as a refigerant. In addition, given that R-134a has a very slow decomposition rate, we feel strongly that any chemical specified in equipment should not outlive its designer.

It should be noted that the LEEDS rating system gives credit for the use of R-134a, and that there has been much debate over how the LEEDS criteria could affect positive refrigerant choices. Having made the recommendation for R-123, Rumsey Engineers would still stand behind any option for refrigerants that the team would like to see investigated and implemented.

Replicability and Pedagogical Aspects

From an architectural standpoint, we proposed a "**visible chiller room**", which would allow building users and visitors to view the clean layout of the chiller room through a large window area. This would contribute to the demonstration and education goals outlined by the Dept. of Natural Resources, and it would allow the major energy systems of the building to be visibly accessible rather than invisible.

Energy labeling of larger energy using equipment - $/year, $/hour, typical $/year, CO2 per year etc. would increase the occupants interest and involvement in energy conservation and awareness. Also, the constant reminder of the energy costs associated with running large office mechanical systems would increase the responsibility felt by the maintenance crew to keep the equipment running efficiently. Overall, our view is that this building should demonstrate efficient HVAC systems in hopes of making them standard and that without this 'exposure' of the systems, much of its effect could be lost.

Performance Monitoring / Continuous Commissioning

As part of the concept behind efficient building mechanical systems, metering the saved energy is critical. The solid proof of power consumption can be used to prove the efficiency of the design so that other buildings can effectively implement similar measures. In addition, monitoring the power consumption and efficiency of key pieces of equipment can help maintenance personnel troubleshoot operations problems and more quickly fix possible efficiency shortfalls.

- Flow Meters - used to control chiller flow and monitor potentially wasted pumping energy
- Power Sensors on key pieces of equipment to record building energy end use
- Space Humidity Sensor(s) - to monitor potential damp conditions to prove indoor air quality

Load Calculations and Energy Simulation

The building's energy end use will be simulated with *DOE2* – a program specifically designed by the Department of Energy for simulating large-scale energy consumption and savings. *Trane Trace* will be used for determining the peak building loads and equipment sizing. *DOE2* is better for annual energy end use predictions while the Trane program is more commonly accepted for building peak load determination. The results of the two will be compared and a small paper will be written on the findings of the comparison.

The energy comparison will also compare a typical office building of similar shape and function to the final, efficient case of this project. In the paper, explanations of inputs and criteria used in calculation will be clarified so that a non-engineer can adequately understand where and how much energy is being consumed by the structure and occupants.

The load calculations from the *Trane Trace* software along with detailed equipment specification sheets will be given to Smith and Boucher for review. Building load and energy end use can be reviewed in depth in the accompanying SD phase Energy Report.

Life Cycle Cost Analysis

We believe that with FSC Smith & Boucher the Missouri Dept. of Natural Resources can have a superior HVAC system at a standard construction cost per square foot. The more initial costs savings that can be passed on to efficient equipment and passive building systems, the more value the mechanical systems will have in reducing the building energy use.

For detailed life cycle cost analyses see the detailed SD phase Energy Report.